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Numerical Simulation and Line Measurement Analysis of Pantograph and Catenary Interaction on Overlap Span of High-Speed Railway

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Abstract

A catenary model of China high speed railway with 4-span overlap is established in this article. Through numerical simulation, the dynamic interaction of pantograph passing through the overlap at the speed of 300 km/h is calculated and analyzed. In addition, the contact force of the train running at the same speed is measured and compared with the simulation results. The simulation results are close to the line measurement results. The dynamic interaction between pantograph and catenary is significantly enhanced at overlap span, which becomes more obvious with the increase of speed.

Keywords: pantograph and catenary system, 4-span overlap, numerical simulation, line measurement.

1 Introduction

The pantograph-catenary (PAC) system is one of the most important components of the electrical locomotive, which is the only way to effectively provide power to the electrical locomotive. During train operation, a good contact between pantograph and catenary should be maintained to ensure the stable current collection. However, there are many weak structures in the overhead contact line (OCL), which will affect the current collection quality of PAC, such as the overlap span. Separating the catenary system into different anchor sections can reduce the occurrence of the accident and facilitate maintenance. However, when the pantograph enters from one anchor section to another, the dynamic interaction between the contact piece and the contact wire will change accordingly.

In recent years, various pantograph catenary models have been developed, which promotes the research on the dynamic interaction relationship between PAC[1]. Subsequently, the influence and optimization of structural parameters[2], geometry and tension[3] on the current collection quality of PAC have been studied. With a deepening understanding of the relationship in PAC, the fluctuation characteristics, the elastic distribution[4] and the irregularity of catenary have also attracted attention. Considering the actual working environment of PAC, the influence of icing, cross wind, temperature stress and external vibration on OCL are obvious. In addition to theoretical research and modeling methods, many bench tests and line tests[5] have been carried out to validate the numerical models. However, these studies mainly focus on the dynamic interaction between PAC in normal spans, ignoring the special sections such as overlap.

Some progress has also been made in the dynamic investigation between PAC at the overlap. Kwon[6] put forward a method to calculate the length of the dropper at the overlap, and compared it with the sample data of the OCL to verify the correctness of the calculation method. Based on the finite element method (FEM), Mei[7] simulated and analyzed the dynamic response of pantograph passing through a five-span overlap. Gregorig[8] established both four- and five- overlap span , and optimized the structural parameters to improve the ability of the pantograph to pass through the overlap smoothly.

In this paper, a four-span overlap model is established. The dynamic characteristics of the pantograph passing through the overlap at different speeds are simulated and analyzed. The simulation data are compared with the on-line test data to verify the correctness of the model.

2 Methods

The four-span overlap is shown in Fig.1. The height point is on the transition mast, and the vertical distance from the contact wire ΔH_1 is 0.04 m. It should be noted that the connecting line of the two height points is not perpendicular to the train running direction. The longitudinal distance between the two height points d is 1.6 m. The height of the second transition mast sub-working branch contact wire is 0.5 m higher than the working branch contact wire i,e, ΔH_2, and the height of the third transition mast sub working branch contact wire is 0.9 m higher than the working branch contact wire, i,e, ΔH_3.

According to the parameters of China high speed railway, a OCL model with four-span overlap is established in ANSYS, as shown in Fig.2. Each individual anchor section has 15 spans with a span of 50 m and the stagger of the catenary is 0.2 m. The red one is Catenary 1 and the blue one is Catenary 2. The catenary model is mainly composed of messenger wire, auxiliary messenger wire, contact wire, dropper and steady arm.

In the FEM model, the mast is simulated by the boundary conditions and both of the ends of the messenger wire and contact wire are pinned. The messenger wire, auxiliary messenger wire, contact wire and steady arm are modeled using Euler-Bernoulli beam. The dropper is modeled by rod element and the slack of dropper is realized by changing the stiffness of the dropper.

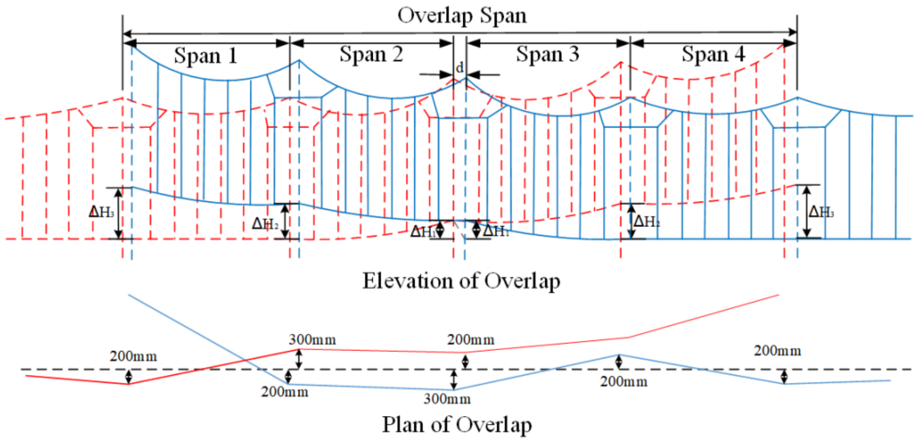
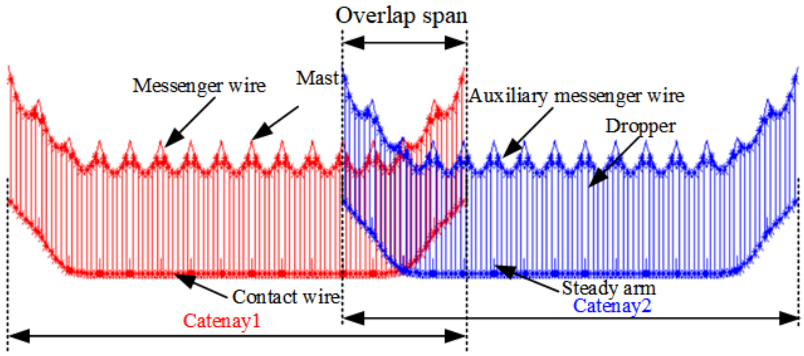


Figure 1. Four-span overlap



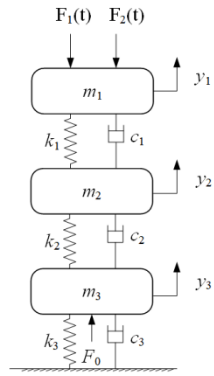


Figure 2. FEM model of four-span overlap   Figure 3. Three-lumped-mass model of pantograph

The widely used three-lumped-mass model is used to simulate the pantograph, as shown in Fig.3. Only the vertical interaction between contact piece and contact wire is taken into account. When the pantograph passes through the overlap span, the contact piece may contact with the contact wire of Catenary 1 and Catenary 2 at the same time, so there will be two contact points. Therefore, it is necessary to establish two contact forces when establishing the contact model between PAC, as depicted in Fig.3.

3 Results

Fig.4 shows the contact force of pantograph passing through one overlap to another overlap at the speed of 300 km/h. The red line is the contact force between the contact piece and Catenary 1, and the blue line is the contact force between the contact piece and Catenary 2. When the pantograph passes through the overlap, the contact force is generated between the contact piece and two different contact wires. At this time, the contact piece is in contact with two contact wires at the same time, which is different from the normal section. When the pantograph enters the overlap, the contact force tends to decrease, and the maximum contact force decreases from 230 N to 200 N. When the pantograph contacts the second contact wire, the contact force at the second wire increases significantly, close to 280 N. Obviously, the dynamic interaction between PAC in the overlap span is significantly enhanced.

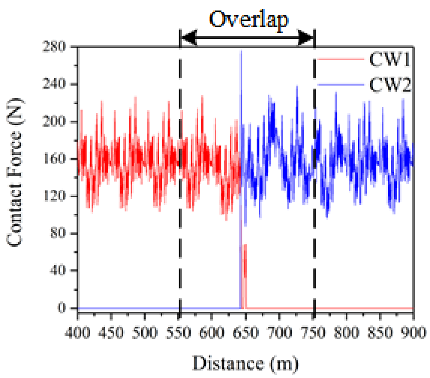


Figure 4. Individual Contact force

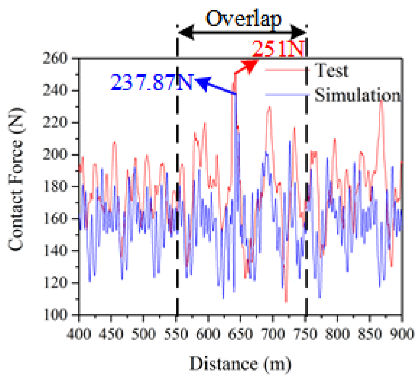


Figure 5. Total contact force

Fig.5 is a comparison between the total contact force (the sum of the contact force between contact piece and two contact wires) calculated by simulation and the actual contact force of on-line test (as shown in Fig.6). The simulated contact force is the filtered result of 20 Hz. The measured contact force signal is a spatially sampled discrete signal, and a sampling point is recorded every 0.25 m of train operation. The simulation speed is 300 km/h and the actual operating speed of the train is 302 km/h. When the pantograph passes through the overlap, the maximum value of contact force appears near the height point. The maximum contact forces simulated and measured are 237.87 N and 251 N respectively. Furthermore, the statistical results of simulated and tested contact force agree well, as shown in Table 1.

	Test [N]	Simulation [N]	Error
Minimum contact force	108	109.93	1.79 %
Maximum contact force	251	237.87	-5.23%
Standard deviation	23.20	19.37	-16.51%

Table 1. Statistical results of test and simulation.

Figure 6. On-line test

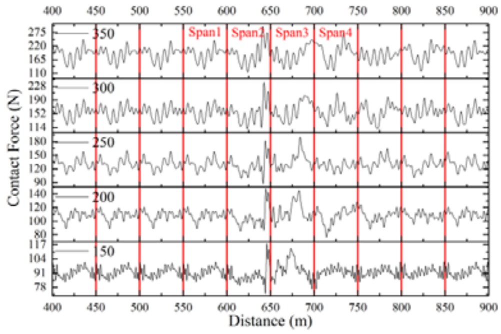


Figure 7. Contact force at different speed

Fig.7 shows the contact force of the pantograph passing through the overlap at the speed of 150～350 km/h. When the pantograph enters Span 2, the contact force decreases significantly, and the contact force reaches the maximum before reaching the height point. When the pantograph enters Span 3, the contact force reaches the peak for the second time.

4 Conclusions and Contributions

This article describes the process of establishing 4-span overlap. A stitched catenary system of China high speed railway with two overlap span is established in ANSYS. Beam element is used to simulate messenger wire, auxiliary messenger wire, contact wire and steady arm, and rod element is used to simulate dropper. The pantograph model is simplified into a three-lumped-mass model, and two contact forces are applied on the contact piece. The contact force of the pantograph passing through the overlap at the speed of 300 km/h is calculated, and statistical results of contact forces are compared with the on-line test data. The simulation results show that the relative error of minimum contact force during operation is 1.79%, the relative error of maximum contact force is -5.23%, and the relative error of standard deviation of contact force is -16.51%. The error of the simulation results is within the acceptable range, which shows the effectiveness of the method. In addition, with the increase of operating speed, the dynamic interaction of pantograph passing through overlap is significantly enhanced, and the vibration characteristics between PAC are also significantly changed.

Acknowledgements

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References

[1] Bruni S, Ambrosio J, Carnicero A, et al. The results of the pantograph–catenary interaction benchmark[J]. Vehicle System Dynamics, 2015, 53(3): 412-435.

[2] Gregori S, Tur M, Nadal E, et al. An approach to geometric optimisation of railway catenaries[J]. Vehicle System Dynamics, 2018, 56(8): 1162-1186.

[3] Zhang J, Liu W, Qiao K, et al. Influence of catenary tension on static elasticity and dynamic contact force between pantograph and catenary[J]. IET Electrical Systems in Transportation, 2017, 7(3): 201-206.

[4] Bruni S, Ambrosio J, Carnicero A, et al. The results of the pantograph–catenary interaction benchmark[J]. Vehicle System Dynamics, 2015, 53(3): 412-435.

[5] Karakose E, Gencoglu M T, Karakose M, et al. A new experimental approach using image processing-based tracking for an efficient fault diagnosis in pantograph–catenary systems[J]. IEEE Transactions on Industrial Informatics, 2016, 13(2): 635-643.

[6] Kwon S Y, Lee K W, Cho Y H. A dropper length calculation method of the elevating span in overlap area[C]//Proceedings of the KSR Conference. The Korean Society for Railway, 2011: 1503-1510.

[7] Mei G, Zhang W, Zhao H, et al. A hybrid method to simulate the interaction of pantograph and catenary on overlap span[J]. Vehicle System Dynamics, 2006, 44(sup1): 571-580.

[8] Gregori S, Gil J, Tur M, et al. Analysis of the overlap section in a high-speed railway catenary by means of numerical simulations[J]. Engineering Structures, 2020, 221: 110963.